

# EMERALD ASH BORER MODELING METHODS FOR FUTURE FOREST PROJECTIONS

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**Abstract.**—The emerald ash borer (*Agrilus planipennis* Fairmaire; EAB) is a nonnative invasive insect that has caused considerable damage to ash (*Fraxinus* spp.) in North America. Unlike invasive organisms that can be mitigated, contained, controlled, or even eradicated, EAB continues to spread across North America. The loss of the North American ash resource is possible considering literature suggests close to 100 percent probability of host tree mortality. We modeled future spatial and temporal changes in forest composition from 2010 to 2060 with and without ash mortality anticipated from EAB spread for the purpose of examining anticipated effects of EAB on tree species composition. To forecast midwest and northeast United States future forest conditions, we utilized Forest Inventory and Analysis (FIA) data, the extent of EAB in the United States and Canada, estimated EAB spread rate, estimated EAB host mortality probability, and models of human population, energy, consumption, land use, and economics. We found that in most cases, EAB will not substantially affect the ecosystem function of future forests measured by FIA because ash comprises a small proportion of midwest and northeast U.S. forests, and it will be replaced by associated species. Although the transition from ash to other species could take decades, forests may eventually recover when associated species replace ash.

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## INTRODUCTION

Knowledge of host tree susceptibility risk and temporal and spatial knowledge of insect spread rates are important for efforts to help mitigate adverse economic and ecological effects of invasive insects on forests (e.g., Tobin et al. 2004). Consequently, modeling EAB spread can drive the decisionmaking process and could help with detecting, monitoring,

and slowing EAB spread (Prasad et al. 2010). EAB ash infestation has negatively affected the economic, ecological, aesthetic, and cultural interests of a variety of stakeholders including forest land owners, landowners in urban areas, tree nurseries, and Native American tribes (e.g., using black ash (*Fraxinus nigra* Marsh.) as a cultural resource for basket weaving) (Poland and McCullough 2006). Private landowners can protect individual ash trees with various chemical treatments but there does not appear to be any effective broad-scale treatment to mitigate the effects of EAB. Projections of future forest composition would be beneficial for forest resource management in North American forests with ash, especially considering the economic and ecological consequences. Research indicates the effects of EAB on North American forests with ash may already be visible in FIA data (Pugh et al. 2011). We used FIA data and EAB current range, estimated spread rate, and host mortality data to project future EAB spread and subsequent

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ash mortality. In this paper, we briefly describe our modeling structure, provide some insight into the intensity and trajectory of the impact of EAB, and discuss consequences for future stand development.

## MODELING METHODS

This document is part of an effort to forecast the effect of current and future societal and natural resource trends on the structure and composition of future forests and to project how those effects alter forest ecosystem services (Shifley et al. 2012). These efforts forecasted future forest conditions for 20 states in the Northern Research Station region by assessing current forest conditions and recent forest changes (USDA Forest Service 2012). Forecasts were created in 5-year increments for the period 2010-2060 and projections of future forests were based on FIA forest-type groups (Wear et al. in press) which were used to group forest types developed from multiple sources including lists from FIA and the Society of American Foresters. Forecasting used a scenario approach with a range of plausible futures responsive to human population distributions, global economic conditions, energy and technology use, climate (combinations of three Intergovernmental Panel on Climate Change [IPCC] scenarios and four General Circulation Models [GCMs]; hereafter referred to as “storylines”), timber harvesting, land use change, other disturbance factors, and natural succession.

By incorporating EAB effects into one of the storylines (the A2 CGCM 3.1 storyline as described in USDA Forest Service 2012), we projected forest changes from 2010 to 2060 with and without the anticipated effects of EAB. We assigned an EAB spread rate of 20 km/year (Prasad et al. 2010) and a host mortality probability estimate of 100 percent (Herms et al. 2010) without any ash regeneration, in order to model the future effects of EAB infestation on black, green (*Fraxinus pennsylvanica* Marsh.), and white ash (*Fraxinus americana* L.) in midwest and northeast U.S. forests. Data from the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine

program and the Canadian Food Inspection Agency were used to identify the core infested area of U.S. counties and Canadian regional municipalities where EAB was detected by 31 December 2010. We forecasted a 20 km/year spread rate from this core infested area from 2010 to 2060 (Fig. 1). Ash is found throughout the midwest and northeast United States but the highest concentrations are located in Maine, Michigan, Minnesota, New York, Pennsylvania, and Wisconsin, so this is where we focused our analyses. Ash mortality was applied for each inventory unit when it was subsumed by EAB spread, and projections commenced in 2015 because the range of EAB as of 31 December 2010 was applied to the 2015 projections. Our projections of future forests were carried out through 2060, but the anticipated EAB spread encompassed the entire midwest and northeast United States by 2050 (Fig. 2). Here, we compare results of a non-EAB (“standard”) scenario to results of the same scenario with the projected EAB effects included (“EAB”).

## RESULTS

Future forest projections suggested a decrease in the number of all trees  $\geq 2.54$  cm diameter at breast height (d.b.h.) by 2060 with the standard model. The EAB model projected a larger decrease over the same period, and it projected the loss of ash in all 20 states to occur by 2050 (Table 1, Fig. 2). Volume projections suggested substantial variation across states (Table 2). The standard model projected smaller volume decreases in most forest-type groups than did the EAB model (Table 3). This trend was apparent with forest-type groups where ash was a major component such as elm-ash-cottonwood (E-A-C), but this was not the case with forest-type groups where ash was a minor component, such as spruce-fir. However, in Maine the standard model projected larger volume decreases in E-A-C than did the EAB model, in Minnesota the standard model projected larger decreases in the oak-hickory forest-type group (O-H) than did the EAB model, and in Pennsylvania the standard model projected larger decreases in O-H than did the EAB model.

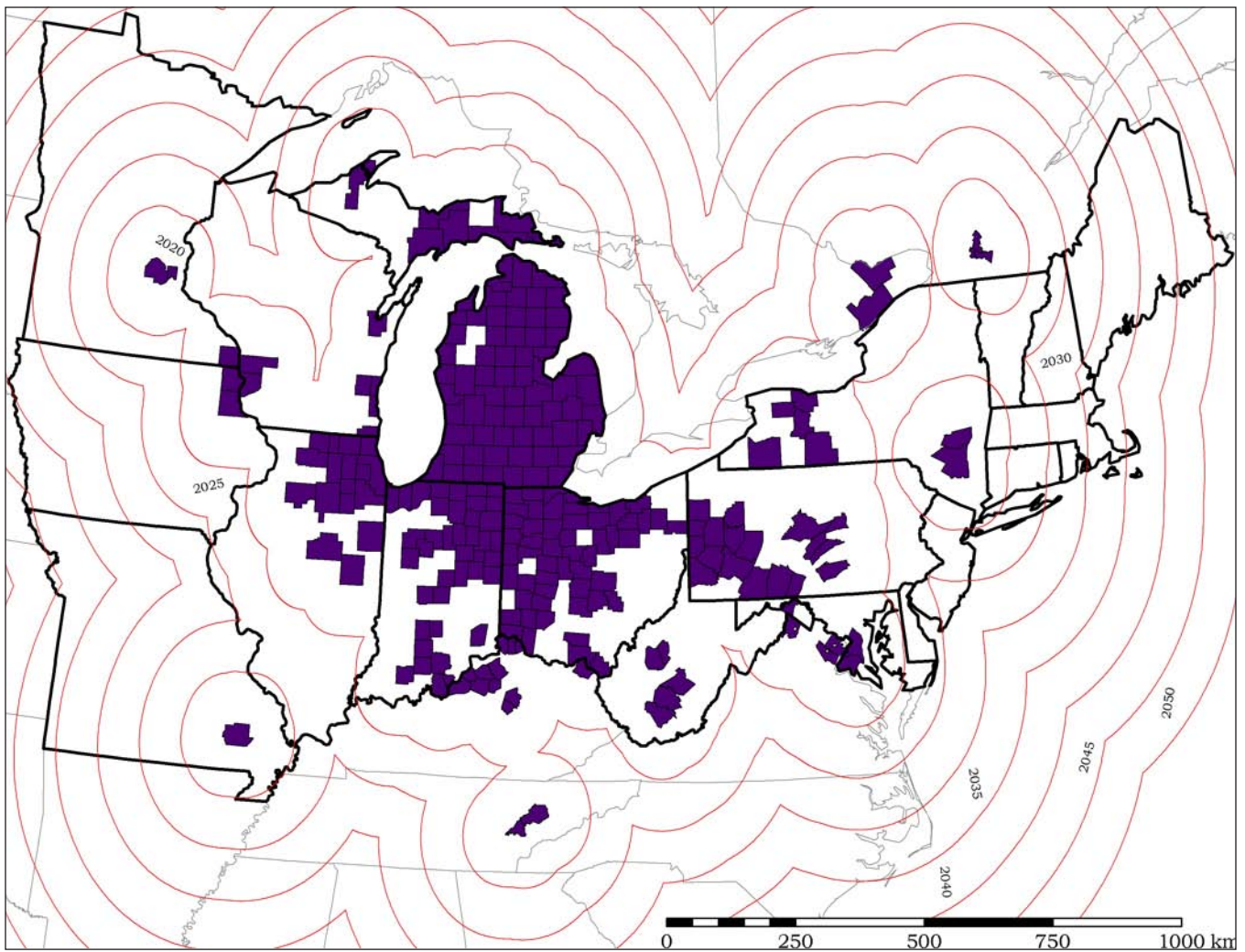


Figure 1.—United States counties and Canadian regional municipalities where EAB was detected by 31 December 2010 are shown in purple and were based on data from USDA Animal and Plant Health Inspection Service, Plant Protection and Quarantine program and Canadian Food Inspection Agency. The projected EAB spread rate of 20 km/year is shown in 5-year intervals in dark red lines, whereby the innermost (from center) dark red spread line corresponds with 2020 and outermost 2050.

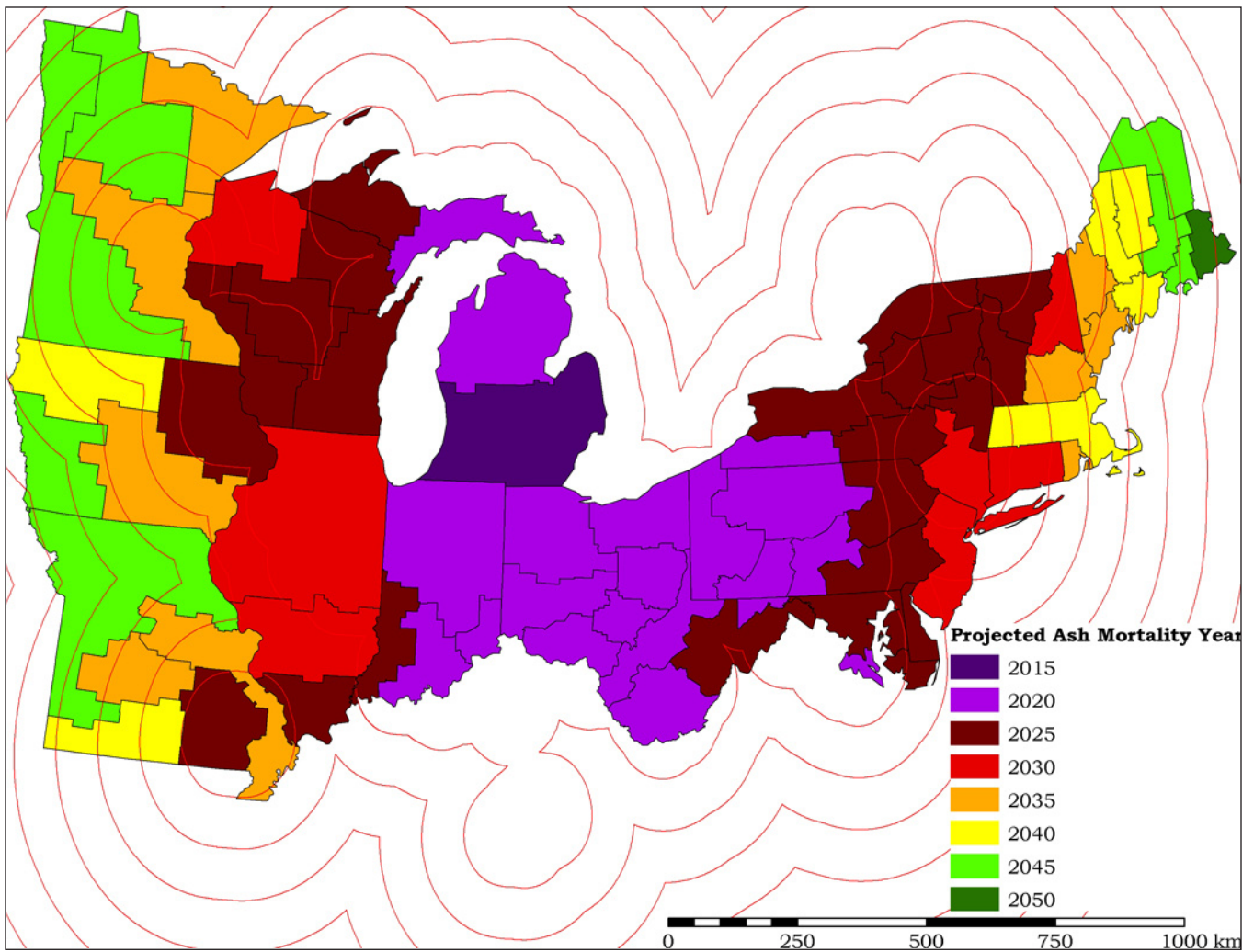


Figure 2.—Using dates when EAB spread subsumes each inventory unit (black lines within each state), the projected mortality of ash due to EAB is shown for each midwest and northeast FIA inventory unit. EAB spread in New York, Vermont, New Hampshire, and Maine was influenced by EAB infestations in Ontario and Québec, Canada regional municipalities. EAB spread was not influenced by EAB infestations in Tennessee, Kentucky, or Virginia or in other Canadian locations. This projection assumed EAB spread caused ash mortality once the spread subsumed each inventory unit.

Table 1.—Total number of all trees  $\geq 2.54$  cm d.b.h. on forest land in billions by state, year, and model. See text for model descriptions.

State	2010 number of all trees $\geq 2.54$ cm d.b.h. (billions)	Standard model		EAB model	
		2060 number of all trees $\geq 2.54$ cm d.b.h. (billions)	Percent change (2010 to 2060)	2060 number of all trees $\geq 2.54$ cm d.b.h. (billions)	Percent change (2010 to 2060)
Maine	23.32	20.87	-11	20.54	-12
Michigan	14.03	12.25	-13	11.25	-20
Minnesota	13.06	11.37	-13	9.97	-24
New York	12.19	11.54	-5	10.93	-10
Pennsylvania	8.35	7.27	-13	6.94	-17
Wisconsin	10.92	9.56	-12	8.67	-21
Total	81.87	72.86	-11	68.30	-17

**Table 2.—Total volume of all trees ≥12.70 cm d.b.h. on forest land in million cubic meters, by state, year, and model. See text for model descriptions.**

State	2010 percent of total land area in forest land	2010 volume	Standard model		EAB model	
			2060 volume	Percent volume change	2060 volume	Percent volume change
Maine	89	721.53	765.77	6	735.67	2
Michigan	55	893.47	970.97	9	927.14	4
Minnesota	33	512.51	634.39	24	591.84	15
New York	63	1,121.59	1,197.25	7	1,152.14	3
Pennsylvania	58	1,002.02	986.75	-2	984.24	-2
Wisconsin	48	658.13	817.09	24	766.66	16
Total	53	4909.25	5372.22	9	5157.69	5

**Table 3.—Total volume of trees ≥12.70 cm d.b.h. on forest land in million cubic meters, and percent change in total volume of trees on forest land, by state, forest-type group, and model. See text for model descriptions.**

Maine				New York			
Forest-type group	2010 total volume	Percent change 2010-2060		Forest-type group	2010 total volume	Percent change 2010-2060	
		Standard model	EAB model			Standard model	EAB model
White-red-jack-pine	77.38	0	1	White-red-jack-pine	90.04	22	3
Spruce-fir	212.64	11	4	Spruce-fir	35.84	17	33
Oak-hickory	18.30	13	5	Oak-hickory	167.49	71	46
Elm-ash-cottonwood	11.54	-45	-23	Elm-ash-cottonwood	57.72	-79	-83
Maple-beech-birch	308.64	10	5	Maple-beech-birch	663.28	1	3
Aspen-birch	67.19	-13	-9	Aspen-birch	29.89	-57	-61

Michigan				Pennsylvania			
Forest-type group	2010 total volume	Percent change 2010-2060		Forest-type group	2010 total volume	Percent change 2010-2060	
		Standard model	EAB model			Standard model	EAB model
White-red-jack-pine	100.58	52	49	White-red-jack-pine	26.46	16	15
Spruce-fir	109.21	-6	-9	Spruce-fir	1.32	-25	-25
Oak-hickory	150.92	1	0	Oak-hickory	538.25	1	-3
Elm-ash-cottonwood	84.98	-7	-28	Elm-ash-cottonwood	14.62	55	-15
Maple-beech-birch	313.00	8	6	Maple-beech-birch	364.00	-8	-1
Aspen-birch	105.35	2	-9	Aspen-birch	10.37	61	53

Minnesota				Wisconsin			
Forest-type group	2010 total volume	Percent change 2010-2060		Forest-type group	2010 total volume	Percent change 2010-2060	
		Standard model	EAB model			Standard model	EAB model
White-red-jack-pine	49.70	21	23	White-red-jack-pine	80.51	126	114
Spruce-fir	79.76	5	-3	Spruce-fir	40.27	10	4
Oak-hickory	91.12	-23	-8	Oak-hickory	182.85	4	7
Elm-ash-cottonwood	52.00	115	39	Elm-ash-cottonwood	58.27	23	2
Maple-beech-birch	53.77	-18	-26	Maple-beech-birch	180.86	-4	-7
Aspen-birch	170.84	48	44	Aspen-birch	88.20	11	-1

## DISCUSSION

There was little or no difference in the number of all trees  $\geq 2.54$  cm d.b.h. and volume between the standard and EAB models in states where ash was not an important genus (e.g., Maine, 2 percent of total growing stock volume) (Table 4). Differences between the standard and EAB models were greater in states where ash was a more prominent genus (e.g., Minnesota, 8 percent of total growing stock volume). For example, the effect of ash mortality on differences between the EAB and standard models was most apparent in Minnesota and least apparent in Maine because ash contributed a much larger portion of the total growing-stock volume in Minnesota than it did in Maine. This led to a greater difference between the standard and EAB models in Minnesota than in Maine. Ash represented a larger component of forest and was predominately found in E-A-C forests in Minnesota, so the majority of changes involved forest types in the E-A-C forest-type group. Similarly, Minnesota volume differed between the standard and EAB models (Tables 2 and 3). Ash represented a very small component of forest and was more prevalent in O-H than E-A-C forests in Maine, so most changes in forest types did not involve forest types in E-A-C forests. Therefore, in Maine the projected number of all trees  $\geq 2.54$  cm d.b.h. and volume were similar for both the standard and EAB models, indicating that the EAB model did not appear to substantially alter Maine's E-A-C projections trajectory. Maine O-H

volume trends between the standard and EAB model results were similar as well. Maine standard and EAB model results for E-A-C and O-H forests were probably similar because ash represented a very small proportion of total growing stock. The forest changes predicted by the standard model were based on trends observed between FIA inventories prior to 2010. For the standard model, those trends greatly influenced the probability of forest compositional changes, including transitioning into or out of forest type-groups with ash such as E-A-C or O-H. For example, the Minnesota standard model projected an increase in E-A-C volume because E-A-C volume increased between recent prior inventories. Likewise, the Maine standard model projected a decrease in E-A-C volume because E-A-C volume decreased between recent prior inventories. For the same reason, the Michigan standard model projected a decrease in E-A-C forests. Considering EAB has been established in Michigan since the early 1990s (Siegert et al. 2007), the decrease between recent inventories may have been partly due to EAB effects on ash.

We summarized the effects of EAB on the number and volume of ash trees for the broad category of forest-type groups and the large scale of states. It is important to consider geographic differences in the composition of each forest-type group since we analyzed changes by forest-type group. For example, ash does not comprise a substantial amount of any forest-type group

**Table 4.—Total volume of growing-stock trees and total volume of ash growing stock  $\geq 12.70$  cm d.b.h. on forest land, in million cubic meters, by state.**

State	2010 total trees growing-stock volume	2010 ash trees growing-stock volume	2010 ash percentage of growing-stock volume
Maine	673.66	14.87	2
Michigan	827.05	40.08	5
Minnesota	443.82	35.11	8
New York	1032.29	76.11	7
Pennsylvania	939.29	46.54	5
Wisconsin	601.61	37.15	6
Total	4517.71	249.86	6

in Maine, Minnesota E-A-C is comprised mainly of green and black ash, and ash might comprise a larger portion of O-H than E-A-C in other states. Our modeling suggested the transition from ash to other species could progress slowly as ash is replaced by a variety of associated species, despite our assumption that EAB will cause 100 percent ash mortality. Our modeling suggested that EAB effects in non-urban forests measured by FIA may not cause forest-type group changes because associated species not prone to EAB infestation have the potential to offset the loss of ash trees and their associated volume. On the other hand, EAB infestation could lead to canopy gaps and facilitate an increase in native and nonnative invasive plant species (Gandhi and Herms 2010). Ultimately, our modeling may not apply to urban areas not measured by FIA, where there could be a larger impact due to the extensive distribution of urban ash.

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